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PHYSICAL-CHEMICAL TREATMENT OF MUNICIPAL WASTEWATER

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Robert A. Taft Water Research Center
Cincinnati, Ohio

October 1970

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ABSTRACT

Physical-chemical treatment of the District of Columbia raw wastewater in a 100,000 gal/day pilot plant with a 3.2:1 diurnal flow variation consisted of two-stage lime precipitation with intermediate recarbonation, filtration, pH control, ion exchange, and carbon adsorption. The complete system removed 98% of the phosphorus, 95% of the organics and 78% of the total nitrogen.

Lime treatment with approximately 350 mg/l of CaO in a flocculator-clarifier at a maximum overflow rate of 1460 gal/day/ft^2 increased the wastewater pH to above 11.5, removed approximately 96% of the phosphorus and 80% of the BOD, TOC, and COD. Recarbonation with 120 mg/l of CO_2 and with 5 mg/l of Fe^{+++} as a flocculant reduced the pH to 10 and precipitated excess Ca^{++} as $CaCO_3$. The $CaCO_3$ was settled in a second stage at a maximum overflow rate of 1770 gal/day/ft^2.

Filtration through 18" of 0.9 mm coal and 6" of 0.45 mm sand decreased solids to usually less than 5 mg/l and phosphorus to 0.15 mg/l of P. Biological growth occurred on the filters at pH 10. Addition of 10 mg/l of chlorine to the influent of the filter controlled the growth and produced 50 hour filter runs. Additional CO_2 decreased the pH to 7-8 before ammonia removal by ion exchange.

The clinoptilolite exchange mineral reduced the ammonia to less than 1 mg/l as NH_3-N. Hot air stripping of the lime-salt regenerant transferred the ammonia into the atmosphere. Carbon adsorption reduced

the residual organics to an average of 5 mg/l of BOD, 6 mg/l of TOC, and 13 mg/l of COD. The 15-20 mg/l of soluble BOD entering the adsorbers produced anaerobic biological growth on the carbon. Carbon loadings of 0.41 pounds of COD per pound of carbon occurred.

With CO_2 production from incineration of solids and recalcination of lime, the approximate cost of treatment for organic and phosphorus removal in a 300 MGD plant is 23¢/1000 gal. Preliminary costs for NH_4^+ removal by ion exchange is estimated at 10¢/1000 gal.

Keywords:

physical-chemical treatment

selective ion exchange

lime precipitation

carbon adsorption

nitrogen removal

phosphorus removal

PHYSICAL-CHEMICAL TREATMENT OF MUNICIPAL WASTEWATER*

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In the early work on advanced waste treatment of secondary effluents, the product water from granular carbon treatment contained organic materials apparently refractory to carbon adsorption (1). Addition of chemical clarification to the tertiary treatment system (2) for phosphorus removal eliminated from secondary effluents most of the organics refractory to adsorption and produced water, after carbon adsorption, with residual total organic carbon (TOC) concentrations of less than 1 mg/l. The clarification with lime or alum insolubilized the phosphorus and flocculated the colloidal organic and phosphorus materials that were too small to efficiently filter and too large to diffuse into the pores of the carbon granule. A primary effluent, fed to that tertiary treatment system, revealed that clarification and filtration to remove the colloidal material from the primary effluent also produced moderately low residual organic concentrations after carbon adsorption.

Recently, several laboratory and pilot scale studies (3, 4, 5, 6, 7, 8, and 9) have been completed on physical-chemical treatment of raw

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or primary wastewater. The physical-chemical treatment in these studies usually consisted of chemical clarification and dual or multi-media filtration for solids and phosphorus removal, and granular or powdered carbon adsorption to remove the dissolved organics. Physical-chemical treatment also removed particulate nitrogen by clarification, soluble organic nitrogen by adsorption, and nitrate, if present, by biological denitrification on the carbon.

In domestic raw wastewaters, however, most of the soluble nitrogen exists as ammonia or its predecessor urea, and is not removed by clarification or adsorption. Three physical-chemical processes are available for ammonia removal: air stripping of the water above pH 10.5 (10), breakpoint chlorination (11), and selective ion exchange (12).

Air stripping of the ammonia is not effective in cold weather. Calcium carbonate scaling gradually decreases its removal efficiency and increases its maintenance costs in all seasons. Breakpoint chlorination and selective ion exchange, individually or in combination, provide potential all-weather processes for ammonia removal and may be included in the physical-chemical treatment system.

In recent studies on physical-chemical treatment, the clarification process on either primary effluent or raw wastewater employed lime precipitation or metallic salts, such as $FeCl_3$ or alum. In lime precipitation, two treatment options are available: the two-stage high pH lime process (13), usually above pH 11.5, with intermediate recarbonation to remove excess calcium ions from the primary (first) stage, and the single stage precipitation (8) at pH as low as 9.5. The high pH lime process

was usually applied in waters of moderate alkalinity (100-200 mg/l as $CaCO_3$) and produced efficient solids removal and very low phosphorus residuals of less than 0.2 mg/l as P. In hard waters with alkalinities above 250 mg/l, the low pH single-stage lime process produced efficient solids removal and phosphorus residuals of approximately 0.5 mg/l. In water with moderate alkalinities, the low pH lime process required supplemental flocculants, such as polymers or $FeCl_3$, to produce efficient clarification and phosphorus residuals of approximately 1 mg/l. Ferric chloride, with or without polymer, efficiently clarified raw or primary wastewater (9) and produced phosphorus residuals of 0.6 to 1 mg/l.

After the removal of the colloidal substances by clarification and filtration, carbon initially physically adsorbed most of the dissolved organics. In continuous treatment, the build-up of soluble organic material on the carbon rapidly promoted substantial biological activity within the adsorption system and degraded the product quality.

The desirability of biological activity in the adsorption system especially with raw wastewater has not been determined. Microbial growth on the carbon converted the carbon columns into submerged anaerobic trickling filters. The growth also occurred on powdered carbon that was recirculated (14). The biological activity on carbon may remove highly water soluble and poorly adsorbable organics from the water and, as has been reported (15), increased the carbon loading before regeneration.

However, the metabolic end products sluffing from the carbon degraded the water quality by increasing both the residual solids and organic concentrations (2). The microbial slimes coated the carbon

granules and probably reduced the amount of pore surface available for physical adsorption. The anaerobic conditions also produced hydrogen sulfide and released ferrous ion from the carbon (16).

Pure oxygen was added to the adsorption system to eliminate the anaerobic conditions (16), but the oxygen stimulated heavy aerobic growth and increased the backwashing and pressure losses across downflow columns. Expanded upflow beds of carbon have been employed to minimize pressure losses and backwash requirements (9), but the microbial end products were still released into the product water and the slimes coated the carbon granules.

While physical-chemical treatment has been applied to both raw wastewater and primary effluents, it is likely to be applied directly to raw wastewater as the more economical system. Thus, a study of physical-chemical treatment is being conducted on domestic raw wastewater at the FWQA-DC Pilot Plant in Washington, D.C. Since very low phosphorus residuals are needed, the two-stage high pH lime process is employed for clarification. Downflow granular carbon columns are used for removal of the dissolved organics;selective ion exchange is used for ammonia removal.

PILOT SYSTEM

The automated pilot system (Figure 1) consists of cyclone degritting, two-stage (high pH) lime precipitation with intermediate recarbonation, dual-media filtration, pH control, selective ion exchange, and downflow granular carbon adsorption. The precipitation process is designed for a nominal capacity of 100,000 gallons per day; the filtra-

tion, ion exchange, and carbon adsorption processes for 50,000 gallons per day.

A flow controller impresses a diurnal variation of approximately 3.2:1 maximum to minimum flow across the clarification process. Flow splitter boxes and level controllers reduce the flow from the precipitation process to the hydraulic capacity of the subsequent treatment processes and maintain a diurnal variation. The flow variations, detention times, and hydraulic loading for the processes are described in Table 1.

In the first stage of the precipitation process, raw wastewater, lime slurry at a dosage of approximately 350 mg/l as CaO, and recycled solids are turbine-mixed at 13 rpm (average reaction time of 40 minutes) in the internal reactor of an upflow flocculator-clarifier. The lime increases the wastewater pH to above 11.5 and precipitates bicarbonate, phosphate, and magnesium ions from the water (equations 1-3).

1. $Ca^{++} + HCO_3^- + OH^- \longrightarrow CaCO_3 + H_2O$
2. $5Ca^{++} + 3H_2PO_4^- + 7OH \longrightarrow Ca_5OH(PO_4)_3 + 6H_2O$
3. $Mg^{++} + 2OH^- \longrightarrow Mg(OH)_2$

Sludge from the slurry pool at the bottom of the clarifier is recycled at a rate equal to 10% of the average influent flow and produces solids concentrations within the reactor of 3000-5000 mg/l. Waste rates of approximately 1.5% of the influent flow with solids concentrations of 30,000 to 50,000 mg/l maintain the solids balance of the slurry pool.

The limed water, after sedimentation, flows through an open channel to recarbonation. Carbon dioxide, added at an average dose of 120 mg/l below a turbine operating at 171 rpm, reduces the wastewater pH to 10, and

with an average contact period of 15 minutes, precipitates the excess calcium ions added in the liming (first) stage (equation 4).

4. $Ca^{++} + CO_2 + 2OH^- \longrightarrow CaCO_3 + H_2O$

Five mg/l of ferric ions, added in the first of two external 24-minute flocculation basins, each turbine-mixed at 22 rpm, forms $Fe(OH)_3$ and flocculates the precipitated calcium carbonate. After flocculation, the water flows to a perpherial feed circular settler. Settled slurry recycled from the bottom of the settler to recarbonation at a flow rate equal to 10% of the average influent flow provides nuclei for the calcium carbonate precipitation in the recarbonation tank. Wasting at flows equal to 1.5% of the influent maintains the solids balance of the slurry pool in the settler.

The overflow from the second stage settler, is split and pumped to a destribution box ahead of two filters. It then flows by gravity through two dual-media filters packed with 18 inches of 0.9 mm coal and 6 inches of 0.45 mm sand. When pressure losses across a filter exceeds 9 feet of head, a surface wash at 3 gpm/ft^2 and a sequenced backwash at up to 20 gpm/ft^2 automatically cleans the filter for ten minutes and returns it to service.

After filtration, carbon dioxide reduces the pH of the filtered water to 7-8 in the pH control tank. The water then is pumped to the ion exchange or to the carbon adsorption processes. The trailer-mounted ion exchange system is not fully automated and requires continuous operator surveillance for efficient ammonia removals. Thus, the exchange system is operated intermittently and not always at peak efficiency.

In the process, two exchange columns, each packed with 4.5 feet of 16 by 50 mesh clinoptilolite are operated in series with a third column on standby or in regeneration. Spent exchange columns are regenerated by recycling a lime and sodium chloride brine through the column. An air stripping column, which may be heated in winter, continuously removes the ammonia from the recycled brine during regeneration. The first column in the exchanger series is usually regenerated once a day and thus, each column is on stream for about 48 hours. Approximately 0.16 pounds of NaCl and 0.5 pounds of CaO are employed in the regenerant brine for each thousand gallons of treated water.

The flow from either the ion exchange process or from the pH control tank is pumped through four down flow carbon columns each packed with 840 pounds of 8 by 30 mesh granular carbon. The carbon is supported by a 50 mesh stainless-steel screen on a gravel bed. The first column is backwashed and surface-washed on a daily basis with a quantity of water equal to about four percent of the product water. After four months of operation, a high pH (11.5) was substituted on alternate days for the product water used in the bac wash to minimize biological activity on the carbon. The other columns are also washed once a week with the high pH water. To simulate two-stage carbon treatment, the spent carbon is replaced with virgin carbon in two columns at a time. The carbon is not regenerated.

ANALYTICAL PROCEDURES

In the first four months of the study, all samples for analysis were manually composited over 24 hours. To reduce the analytical load,

samples for Ca^{++}, Mg, total phosphorus, NH_3, COD, and TOC were then composited over 48 hours for the last two months of operation. Samples for BOD, TKN, suspended solids, and $NO_3^- + NO_2^-$ were always composited over 24 hours. During compositing, all samples were stored at 3°C to minimize biological activity.

In the laboratory, the total phosphorus was determined by the persulfate method (17); BOD_5 by the probe method (18). The Ca^{++} and Mg^{++} analyses was measured on a Perkin and Elmer Model 303 Atomic Adsorption unit (18). Ammonia (18) and nitrate-nitrite (19) were determined on a Technicon Automatic Analyzer, and the TOC was measured on a Beckman Carbonaceous Analyzer (20). All other analyses employed Standard Methods (21).

CARBON AND SOLIDS REMOVAL

The District of Columbia has a weak domestic wastewater. The intake for the pilot plant was located at the head of the main plant's grit chamber. Solids in the wastewater continually fouled the intake pumps of the pilot plant. After the first month of operation, bar screens were placed over the intake. Rags and other refuse clogged the screens and filtered solids from the water. The pilot plant's efficient cyclone degritter also removed solids from the influent. Thus, the feed to the physical-chemical pilot plant contained less solids and particulate organics than the normal raw plant influent.

Physical-chemical treatment produced very consistent removals of organics (Figure 2) and exhibited high operation stability. Regardless of the daily variations in the influent COD concentration in raw wastewater, lime clarification maintained a low effluent COD.

Lime clarification removed approximately 80% of the organics (TOC, BOD, and COD) from the wastewater (Tables 2-4). Filtration increased these removals only slightly (1-4%) producing water containing 15-20% of the original organics. Ion exchange then removed from 15 to 35% of these residual ("soluble") organics, increasing the accumulated organic removals to more than 85%.

With virgin carbon, the adsorption system in the first month removed 75% of the TOC, 78% of the BOD, and 80% of the COD entering the columns with average residuals of 3.7 mg/l of BOD and TOC and 8.2 mg/l of COD. Adsorption increased the overall organic removals to 97 to 98%.

With loading and biological growth in the fourth month, the carbon removed only 55% of the influent (soluble) TOC, 22% of the BOD_5, and 56% of the COD with average residuals of approximately 8 mg/l for BOD_5 and TOC and 19 mg/l for COD. The overall removals through the plant decreased to between 91 and 94%. The spent carbon (the first half of the carbon) was replaced (Figure 2) at the end of the fourth month (June). The COD loading (Figure 3) on the spent carbon was 0.41 lbs. of COD per lb. of carbon; the TOC loading, 0.15 lbs. of TOC per lb. of carbon.

The replacement of the spent carbon reduced the organic residuals for the fifth month (July) to approximately those of the first month (March). The exchange process relocated in August after carbon adsorption did not significantly remove additional organics from the adsorption column effluent. For six months of operation, the physical-chemical plant removed approximately 95% of the TOC, BOD and COD with average residuals of 6 mg/l of TOC, 5 mg/l of BOD, and 13 mg/l of COD.

As with organic removal, lime clarification produced consistent solids removals (Figure 4). In six months of operation, lime clarification removed about 91% of the suspended solids (Table 5). Filtration increased the removals to 97%. Further decreases in suspended solids did not occur as the removals across the complete plant consistently averaged 97% with about 5 mg/l of residual suspended solids.

NUTRIENT REMOVAL

Lime clarification consistently removed 97% of the total phosphorus from the raw wastewater with only occasional small variations in the daily phosphorus residuals (Figure 5). In March, lime clarification reduced the total phosphorus (Table 6) to 0.45 mg/l as P. Treatment through adsorption further reduced the total phosphorus to 0.21 mg/l (98% removal). As the water temperature increased in the summer, the total phosphorus residuals gradually decreased to 0.17 mg/l after clarification, and after complete treatment to 0.08 mg/l. For the complete study, physical-chemical treatment removed 98% of the total phosphorus with an average phosphorus residual of 0.15 mg/l.

The raw wastewater in the District of Columbia contained chiefly organic nitrogen and ammonia with only about 0.05 mg/l of nitrate nitrogen. Lime precipitation removed an average of 31% of the total nitrogen (TKN and nitrate) from the water (Table 7). The nitrogen removed in clarification was approximately 75% organic (particulate) and 25% (8% of the total original nitrogen) ammonia. The small but consistent ammonia removal across clarification probably occurred by diffusion from the water at high pH into the air.

Filtration increased the total nitrogen removal to about 35%. Ion exchange (clinoptilolite) essentially removed only ammonia from the wastewater. With careful operator surveillance, the exchange process (Figure 6) reduced the NH_3-N to less than 1 mg/l with removals greater than 90%. When unattended, the ammonia residuals in the exchange effluent increased. Thus, for the first five months with the exchange process ahead of adsorption, the clinoptilolite removed approximately 75% of the ammonia entering the process with nitrogen residuals averaging 2.6 mg/l of NH_3-N and 2.3 mg/l of other nitrogen (4.9 mg/l of total N, Table 7).

Little additional removal of nitrogen occurred in the adsorption process, and for the entire six months of the study, the total nitrogen removal averaged 78%. However, in the first five months, the ammonia concentrations in the water from the ion exchange processes consistently increased after carbon adsorption. The soluble organic nitrogen entering the carbon columns (2.3 mg/l) apparently was partially converted by the biological activity on the carbon to ammonia nitrogen. Thus, for maximum nitrogen removal potential, the exchange process was relocated after carbon adsorption for the last month of the study. The exchange process only removed about 71% of the influent ammonia with an average residual of 3.3 mg/l of NH_3-N, but the amount of other (organic) nitrogen in the exchange effluent (product water) decreased from an average of 2.3 mg/l to 0.8 mg/l. With careful operator surveillance, the exchange process could have reduced the total nitrogen to approximately 2 mg/l and produced a total nitrogen removal of 90%.

BIOLOGICAL ACTIVITY

While the pilot plant included only physical-chemical processes, biological activity occurred within the plant and altered the operation of some of the processes. Two-stage lime precipitation of the D.C. raw wastewater was a very stable process as long as the wastewater pH was above 11.5. If the lime slurry feed to the first stage reactor was interrupted or the lime concentration reduced, the resumption of the appropriate lime dose regained the product water quality within a few hours without biological activity.

As the water temperature increased in the spring and summer, microbial growths, however, occurred throughout the second-stage settler at pH 10. The growths did not reduce clarification removal efficiencies which, in general, improved slightly as the water temperature increased (Tables 2-7).

With efficient lime clarification, filter runs of approximately 50 hours occurred in the early spring. With increasing water temperatures, the growth of biological slimes at pH 10 within the filters and in the effluent from lime clarification gradually decreased the length of the filter runs to less than 12 hours. Ten mg/l of chlorine, added to the influent of the filters to control the slimes restored the filter runs to about 50 hours.

In the ion exchange process, initially located ahead of adsorption, noticeable biological growths did not occur with 20-25 mg/l of BOD entering the columns. The regeneration of the spent exchange mineral every two days with a lime brine at pH 11 undoubtedly prevented appre-

ciable build-up of microbial growths. With the relocation of the exchange process after adsorption, the biological growths leaking from the adsorption process fouled the exchange minerals and increased the regeneration time by about 20% and the lime requirements in regeneration by 10%.

COSTS

The estimated water costs (22) (Table 8) for physical-chemical treatment with solids disposal in a 300 MGD plant is 32.2¢ per thousand gallons. The costs included recalcination of the calcium carbonate from the second sedimentation stage for lime recovery (approximately 50% recovery) and the incineration data were not available and estimates were employed. Laboratory and pilot scale solids handling data is now being determined for the sludges from physical-chemical treatment.

The cost of approximately 23¢ per thousand gallons for carbon, phosphorus and particulate nitrogen removal were based on processes with known chemical technology and with developed large scale equipment. In contrast, the selective ion exchange costs of approximately 10¢ per thousand gallons required an estimation of the bulk production costs and the life of the clinoptilolite. The process also included that of an untried acid adsorption step to remove the ammonia from the stripping air in the regenerant step. Finally, ion exchange technology has not been employed at the scale of large wastewater treatment plant.

SUMMARY

Physical-chemical treatment consisting of two-stage lime precipitation with intermediate recarbonation, filtration, pH control, selective

ion exchange and carbon adsorption removed approximately 95% of the TOC, BOD, and COD, 97% of the suspended solids, 98% of the total phosphorus and 78% of the total nitrogen from the District of Columbia raw wastewater. The pollutant residuals for six months of treatment averaged, 6 mg/l TOC, 5 mg/l of BOD, 13 mg/l of COD, 5 mg/l of suspended solids, 0.15 mg/l of total phosphorus as P, and 4.6 mg/l of total nitrogen.

In the study, lime precipitation removed approximately 80% of the TOC, BOD, and COD, 91% of the suspended solids, 97% of the total phosphorus and 31% of the total nitrogen.

Filtration of the lime clarified wastewater increased the removals of pollutants only slightly (1-6%). As examples, the suspended solids removals increased from 91 to 97%, while the total phosphorus increased from 97 to 98%. As the ion exchange and carbon columns also act as filters, the dual-media filters possible may be omitted from the treatment series without appreciable loss of treatment efficiency. The filters might also be relocated to remove suspended solids in the effluent from carbon adsorption.

In chiefly unattended operation, ion exchange located ahead of adsorption removed 75% of the influent ammonia with an average residual of 2.7 mg/l of NH_3-N. However, with careful operator surveillance, the exchange process reduced the NH_3-N residuals to less than 1 mg/l (greater than 90% removal) and the total nitrogen removal exceeded 85%. The exchange process also removed from 15 to 35% of the residual "soluble" organics from the lime clarified and filtered wastewater, and increased the accumulated organic removals to more than 85%.

With virgin carbon, adsorption removed between 75 and 80% of the organics entering the adsorption columns with average residuals of 3.7 mg/l of BOD and TOC and 8.2 mg/l of COD in the first month. With loading and biological growth, residuals after adsorption increased to 8 mg/l of BOD and TOC, and 19 mg/l of COD for the month before the first replacement of spent carbon. COD loading on the spent carbon was 0.41 pounds of COD per pound of carbon.

The backwashing sequence with high pH (11.5) water applied to the adsorption system in the last two months of operation did not eliminate biological activity in the carbon. Thus, determination of the effect of the biological activity on the product quality requires additional work.

Carbon adsorption removed little nitrogen from the wastewater. When located after ion exchange, the adsorption process consistently increased the residual ammonia concentrations in the product water as biological activity on the carbon converted organic nitrogen to ammonia. Therefore, in the last month of the study, the exchange process was relocated after carbon adsorption to provide maximum nitrogen removal potential.

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REFERENCES

1. Joyce, R. S., Allen, J. B., and Sukenik, V. A., "Treatment of Municipal Wastewater by Packed Activated Carbon Beds." Jour. Water Poll. Control Fed., 38, 813 (1966).

2. Bishop, D. F., et al., "Studies on Activated Carbon Treatment." Jour. Water Poll. Control Fed., 39, 188 (1967).

3. Bishop, D. F., "Advanced Waste Treatment Research at the FWPCA-DC Pilot Plant." Presented at the FWPCA Technical Workshop, Fredericksburg, Va., May 13, 1969.

4. Hager, D. G., and Reilly, D. B., "Clarification-Adsorption in the Treatment of Municipal and Industrial Wastewaters." Jour. Water Poll. Control Fed., 42, 794 (1970).

5. Molof, A. H., and Zuckerman, M. M., "High Quality Reuse Water from a Newly Developed Chemical-Physical Treatment Process." Presented at the 5th International Water Pollution Research Conference, San Francisco (July 1970).

6. Stamberg, J. B., Bishop, D. F., Warner, H. P., and Griggs, S. H., "Lime Precipitation in Municipal Wastewaters." Presented at the 62nd Annual Meeting of AIChE (November 1969).

7. Stander, G. J., and Van Vuuren, L. R. J., "The Reclamation of Potable Water from Wastewater." Jour. Water Poll. Control Fed., 41, 355 (1969).

8. Villers, R. V., Berg, E. L., Brunner, C. A., and Masse, A. N., "Treatment of Primary Effluent by Lime Clarification and Granular Carbon." Presented at the 47th Annual Meeting of ACS, Toronto (May 1970).

9. Weber, W. J., Hopkins, C. B., and Bloom, Jr., R., "Physicochemical Treatment of Wastewater." Jour. Water Poll. Control Fed., 42, 83 (1970).

10. O'Farrell, T. P., Frauson, F. P., Cassel, A. F., and Bishop, D. F., "Nitrogen Removal by Ammonia Stripping." Presented at the 160th National ACS Meeting, Chicago (September 1970).

11. Pressley, T. [illegible] Bishop, D. F., and Roan, S. G., "Nitrogen Removal by Breakpoint Chlorination." Presented at the 160th National ACS Meeting, Chicago (September 1970).

12. Mercer, B. W., et al., "Ammonia Removal from Secondary Effluent by Selective Ion Exchange." Jour. Water Poll. Control Fed., 42, R 95 (1970).

13. O'Farrell, T. P., Bishop, D. F., and Bennett, S. M., "Advanced Waste Treatment at Washington, D.C." Chem. Engr. Prog., Symposium Series 97, 65, 251 (1969).

14. Burns, D. E., "Physical-Chemical Treatment of Municipal Wastewater." Thirteenth Progress Report, FWQA, Contract No. 14-12-585 (August 1970)..

15. English, J. N., et al., "Removals of Organics from Wastewater by Activated Carbon." Presented at the 67th National Meeting of the AIChE, Atlanta (February 1970).

16. O'Farrell, T. P., Stamberg, J. B., and Bishop, D. F., "Carbon Adsorption of Lime Clarified Raw, Primary, and Secondary Wastewaters." To be Presented at the 68th Annual Meeting of AIChE, Houston (March 1971).

17. Gales, M., Julian E., and Kroner, R., "Method for Quantitative Determination of Total Phosphate in Water." Jour. of Am. Water Wks. Assoc., 58, 1363 (1966).

18. "FWPCA Methods for Chemical Analysis of Water and Wastes." U. S. Dept. of the Interior, Fed. Water Poll. Control Adm., Cincinnati (November 1969).

19. Kamphake, L., Hannah, S., and Cohen, J., "Automatic Analysis for Nitrate by Hydrazone Reducation." Water Res., 1, 205 (1967).

20. Schaeffer, R. B., et al., "Application of a Carbon Analyzer in Waste Treatment." Jour. Water Poll. Control Fed., 37, 1545 (1965).

21. "Standard Methods for the Examination of Water and Wastewater." 12th ed., American Public Health Association, New York (1965).

22. Bishop, D. F., O'Farrell, T. P., Stamberg, J. B., and Porter, J. W., "Advanced Waste Treatment Systems at the FWQA-DC Pilot Plant." To be Presented at the 68th Annual Meeting of AIChE, Houston (March 1971).

TABLE 1

OPERATING CONDITIONS

		Flow gal/min.	Hydraulic Loading Rate	Detention Time
Lime Precipitation				
Stage 1	Dry Flow	45 min.	475 gpd/ft^2	
		70 ave.	727 gpd/ft^2	
		105 max.	1100 gpd/ft^2	4.4 hrs.*
	Rain Peak	140	1450 gpd/ft^2	
Stage 2	Dry Flow	45 min.	575 gpd/ft^2	
		70 ave.	885 gpd/ft^2	
		105 max.	1340 gpd/ft^2	2.8 hrs.*
	Rain Peak	140	1770 gpd/ft^2	
Filtration				
	(2 filters)	20 min.	1.7 gpm/ft^2	
		35 ave.	2.98 gpm/ft^2	26.3 min.
		52 max.	4.43 gpm/ft^2	
Selective Ion Exchange				
(Intermittent)		20 min.	2.42 gpm/ft^2	
		35 ave.	4.22 gpm/ft^2	16.0 min.
		52 max.	6.28 gpm/ft^2	
Carbon Adsorption		20 min.	4 gpm/ft^2	
		35 ave.	7 gpm/ft^2	27 min.
		52 max.	10.4 gpm/ft^2	

* Includes mixing and flocculation

TABLE 2

TOC REMOVAL

Month (1970)	Influent mg/l	Clarification Residual mg/l	% Rem.[2]	Filtration Residual mg/l	% Rem.[2]	Ion Exchange[1] Residual mg/l	% Rem.[2]	Adsorption Residual mg/l	% Rem.[2]
March	118	25.5	78	20.1	83	14.9	87	3.7	97
April	102	22.8	77	19.9	81	14.8	85	4.9	95
May	114	18.8	84	16.8	85	13.5	88	8.1	93
June	85	18.1	79	18.5	78	14.5	83	8.3	91
July	78	17.6	78	17.3	78	11.8	82	5.2	93
August	96	17.5	82	18.4	81	6.1	93[3]	7.6	92[3]

1 Intermittent Operation , % removal based on intermittent influent concentration

2 Accumulated % Removal

3 Ion exchange placed after adsorption

TABLE 3

BOD REMOVAL

Month (1970)	Influent mg/l	Clarification Residual mg/l	% Rem.[2]	Filtration Residual mg/l	% Rem.[2]	Ion Exchange[1] Residual mg/l	% Rem.[2]	Adsorption Residual mg/l	% Rem.[2]
March	142	31.4	78	23.7	83	16.7	88	3.7	98
April	126	28.3	78	24.3	81	18.6	85	6.4	95
May	158	26.1	83	19.4	88	12.6	90	6.5	96
June	111	18.1	84	15.1	86	9.6	90	7.5	93
July	99	13.0	86	11.8	88	7.8	92	3.0	97
August	98	16.2	83	13.9	86	4.3	93[3]	4.7	95[3]

1 Intermittent Operation, % removal based on intermittent influent concentration

2 Accumulated % Removal

3 Ion exchange placed after adsorption

TABLE 4

COD REMOVAL

Month (1970)	Influent mg/l	Clarification Residual mg/l	% Rem.[2]	Filtration Residual mg/l	% Rem.[2]	Ion Exchange[1] Residual mg/l	% Rem.[2]	Adsorption Residual mg/l	% Rem.[2]
March	347	66.2	81	53.9	84	41.3	86	8.2	98
April	311	56.3	80	51.8	82	39.2	87	12.7	96
May	299	52.5	83	45.2	85	38.4	90	16.4	95
June	302	48.5	84	44.9	85	38.2	90	18.7	94
July	282	40.4	86	36.1	87	25.6	92	7.8	97
August	289	43.6	85	45.1	84	22.9	93[3]	15.4	94[3]

1 Intermittent Operation, % removal based on intermittent influent concentration

2 Accumulated % Removal

3 Ion exchange placed after adsorption

TABLE 5

SUSPENDED SOLIDS REMOVAL

Month (1970)	Influent mg/l	Clarification Residual mg/l	Clarification % Rem.[2]	Filtration Residual mg/l	Filtration % Rem.[2]	Ion Exchange[1] Residual mg/l	Ion Exchange[1] % Rem.[2]	Adsorption Residual mg/l	Adsorption % Rem.[2]
March	180	19.3	89	4.6	98	7.1	96	2.7	99
April	160	22.7	86	10.3	94	6.4	97	4.6	97
May	164	12.0	93	5.1	97	21	87	6.0	97
June	159	6.3	96	4.6	97	5.1	97	4.3	97
July	144	8.9	94	4.3	97	9.0	96	4.0	97
August	139	17.5	87	4.2	97	7.0	95[3]	5.9	96[3]

1 Intermittent Operation, % removal based on intermittent influent concentration

2 Accumulated % Removal

3 Ion exchange placed after adsorption

TABLE 6

PHOSPHORUS REMOVAL

Month (1970)	Influent mg/l	Clarification Residual mg/l	% Rem.[2]	Filtration Residual mg/l	% Rem.[2]	Ion Exchange Residual mg/l	% Rem.[2]	Adsorption Residual mg/l	% Rem.[2]
March	8.7	0.45	95	0.31	96	0.51	94	0.21	98
April	8.5	0.30	97	0.18	98	0.16	98	0.17	98
May	8.9	0.25	97	0.15	98	0.16	98	0.12	99
June	8.5	0.16	98	0.14	98	0.10	99	0.14	98
July	8.1	0.17	98	0.14	99	0.078	99	0.075	99
August	8.0	0.18	98	0.11	99	.088	99[3]	0.078	99[3]

1 Intermittent Operation, % removal based on intermittent influent concentration

2 Accumulated % Removal

3 Ion exchange placed after adsorption

TABLE 7

NITROGEN REMOVAL

Month (1970)	Influent		Clarification		Filtration		Ion Exchange		Adsorption		% Removals	
	Total N	NH_3-N	Total N	NH_3-N	Total N	NH_3-N	Total N	NH_3-N	Total N	NH_3-N	Total N	NH_3-N
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
March	23.4	13.7	17.1	12.8	16.1	13.0	4.1	1.7	3.2	3.0	86	78
April	20.7	11.3	15.9	10.9	15.1	10.9	5.8	2.7	4.1	3.8	80	66
May	21.0	12.8	14.8	12.1	13.9	11.7	4.9	2.9	5.2	4.0	75	69
June	20.5	12.7	13.4	11.0	13.1	10.6	4.5	2.6	5.1	3.6	75	72
July	20.6	12.1	13.0	10.4	12.2	10.8	5.3	3.3	4.8	3.6	77	70
August	19.7	12.3	13.1	11.4	11.6	10.9	4.1	3.3[1]	11.3	11.2	79	73

1 Ion exchange placed after adsorption

TABLE 8

COSTS
(Cents per Thousand Gallons)[1]

	Influent Pumping & Grit Removal	Lime Treatment	Filtration	Solids Disposal	Carbon Adsorption	Ion Exchange	TOTALS
FUEL	----	0.5	---	1.2	---	---	1.7
ELECTRICITY	0.04	0.4	---	.1	0.3	0.5	1.3
CHEMICALS	----	2.2	0.3	.1	---	2.6	5.2
SUPPLIES	0.04	0.2	0.1	.1	1.9	1.4	3.8
O & M LABOR	0.4	0.6	0.5	0.9	0.6	0.6	3.6
CAPITAL CHARGES[2]	0.6	4.1	1.0	1.5	4.8	4.6	16.6
Totals	1.1	8.0	1.9	3.9	7.6	9.7	32.2

1 Plant size 300 MGD based on June 1970 costs

2 Annual capital cost computed at annual rate of 8% including interest and amortization.

FIGURE 1. - Physical-Chemical Treatment Pilot Plant

INDEPENDENT PHYSICAL CHEMICAL TREATMENT

LIME PRECIPITATION

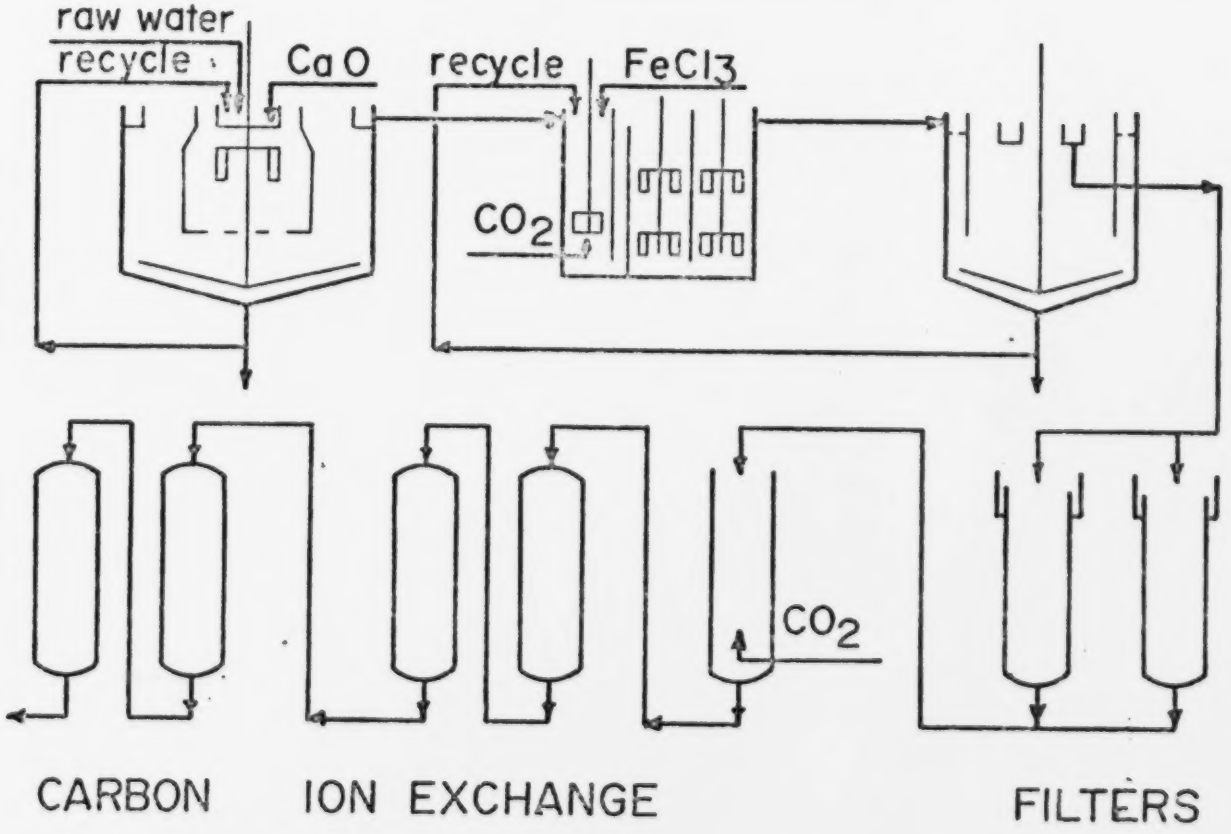


FIGURE 2. - Removals of COD by Physical Chemical Treatment

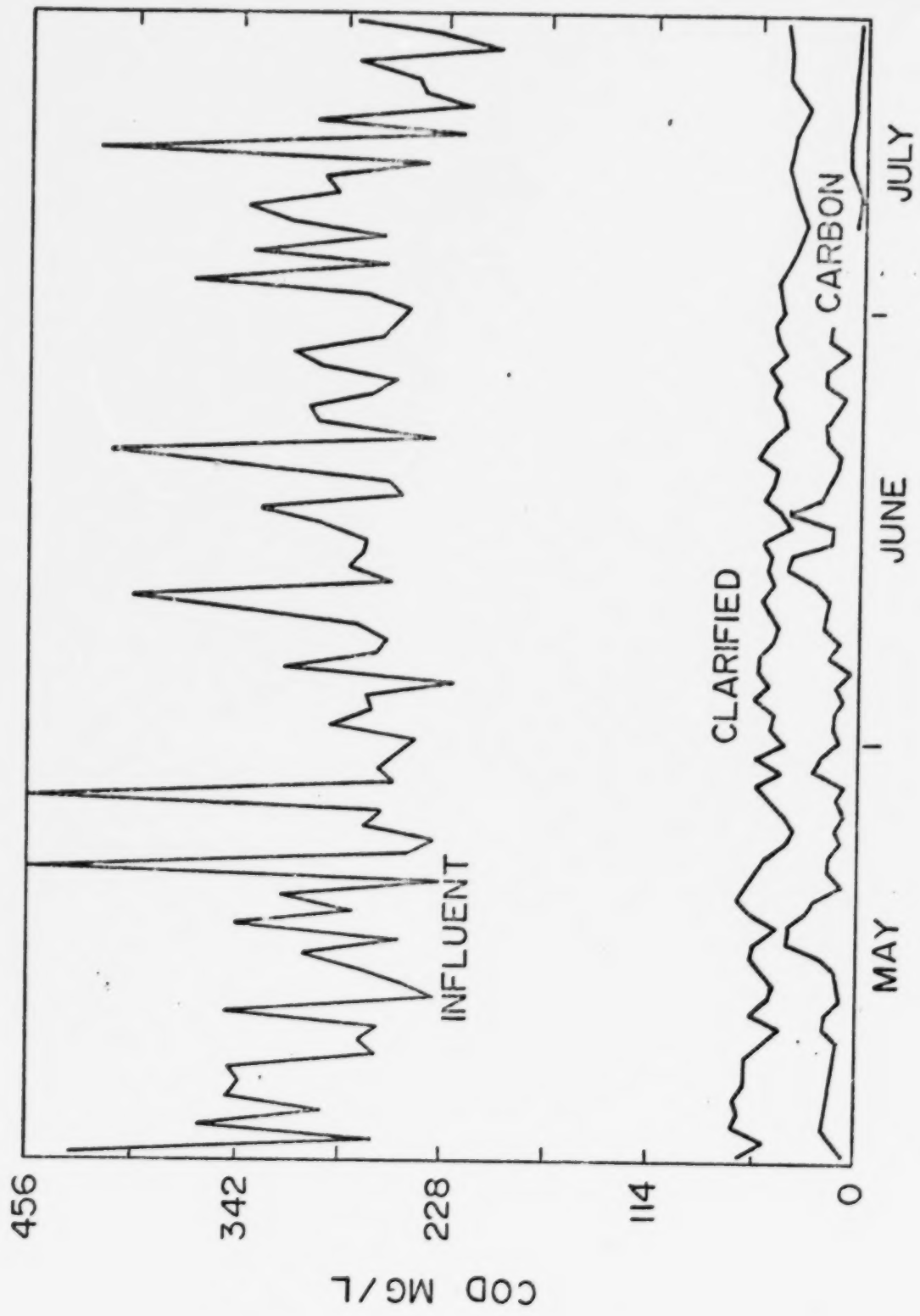

COD MG/L
456
342
228
114
0
INFLUENT
CLARIFIED
CARBON
MAY
JUNE
JULY

FIGURE 3. - COD Loading on Granular Carbon

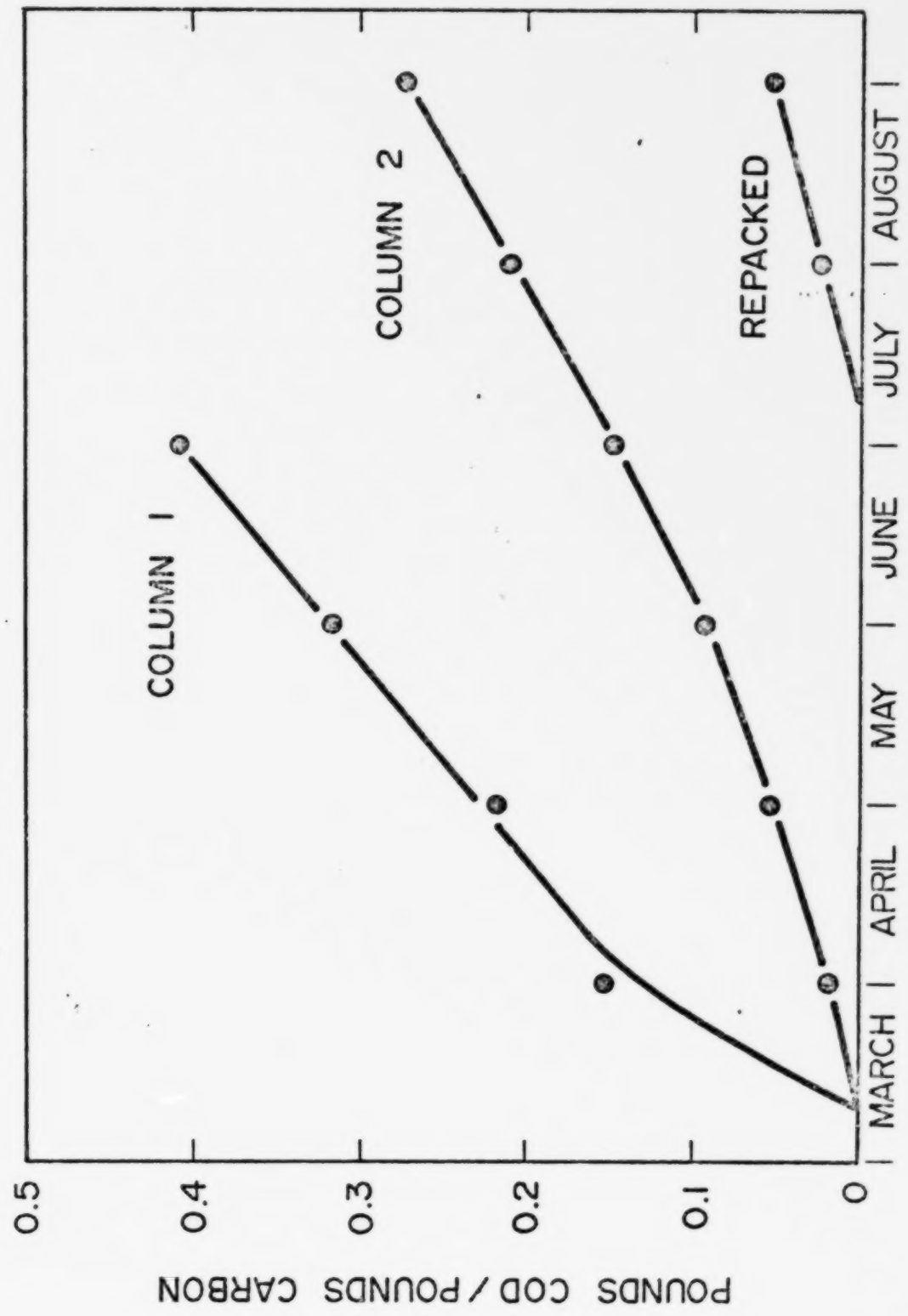

POUNDS COD / POUNDS CARBON
0.5
0.4
0.3
0.2
0.1
0
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
COLUMN 1
COLUMN 2
REPACKED

FIGURE 4. - Removals of Suspended Solids by Lime Clarification

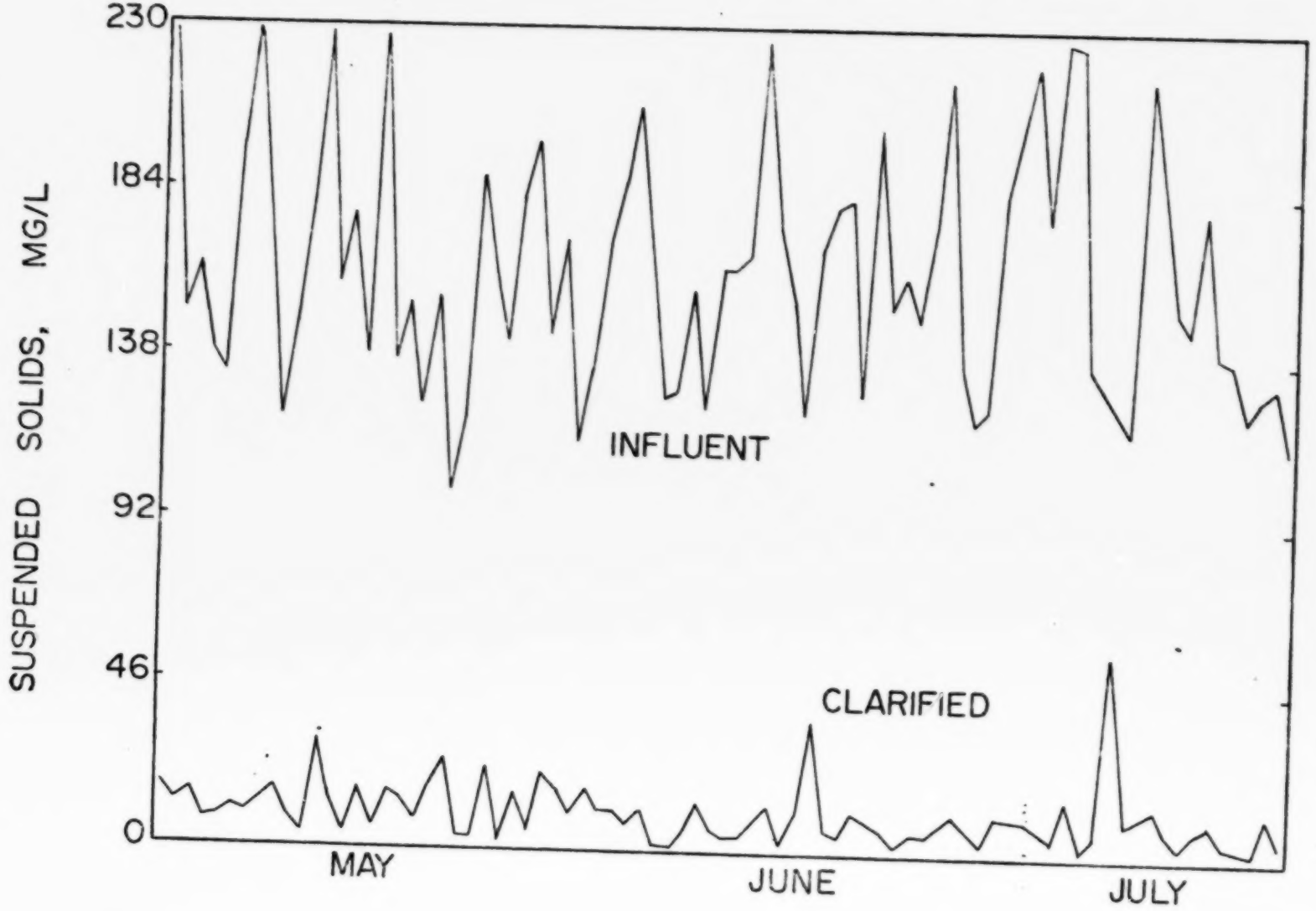

230
184
138
92
46
0
SUSPENDED SOLIDS, MG/L
INFLUENT
CLARIFIED
MAY
JUNE
JULY

FIGURE 5. - Removals of Total Phosphorus by Lime Clarification

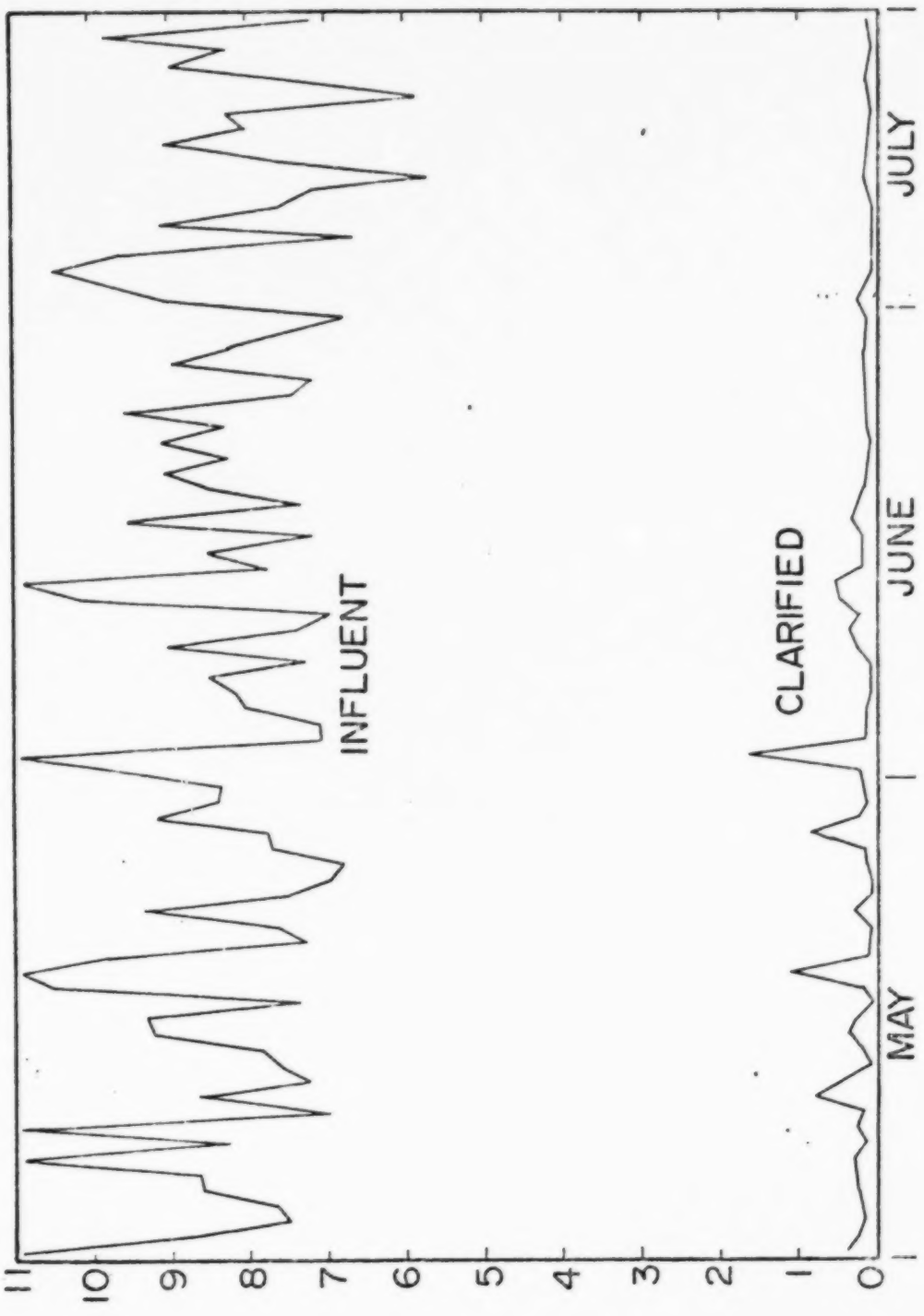
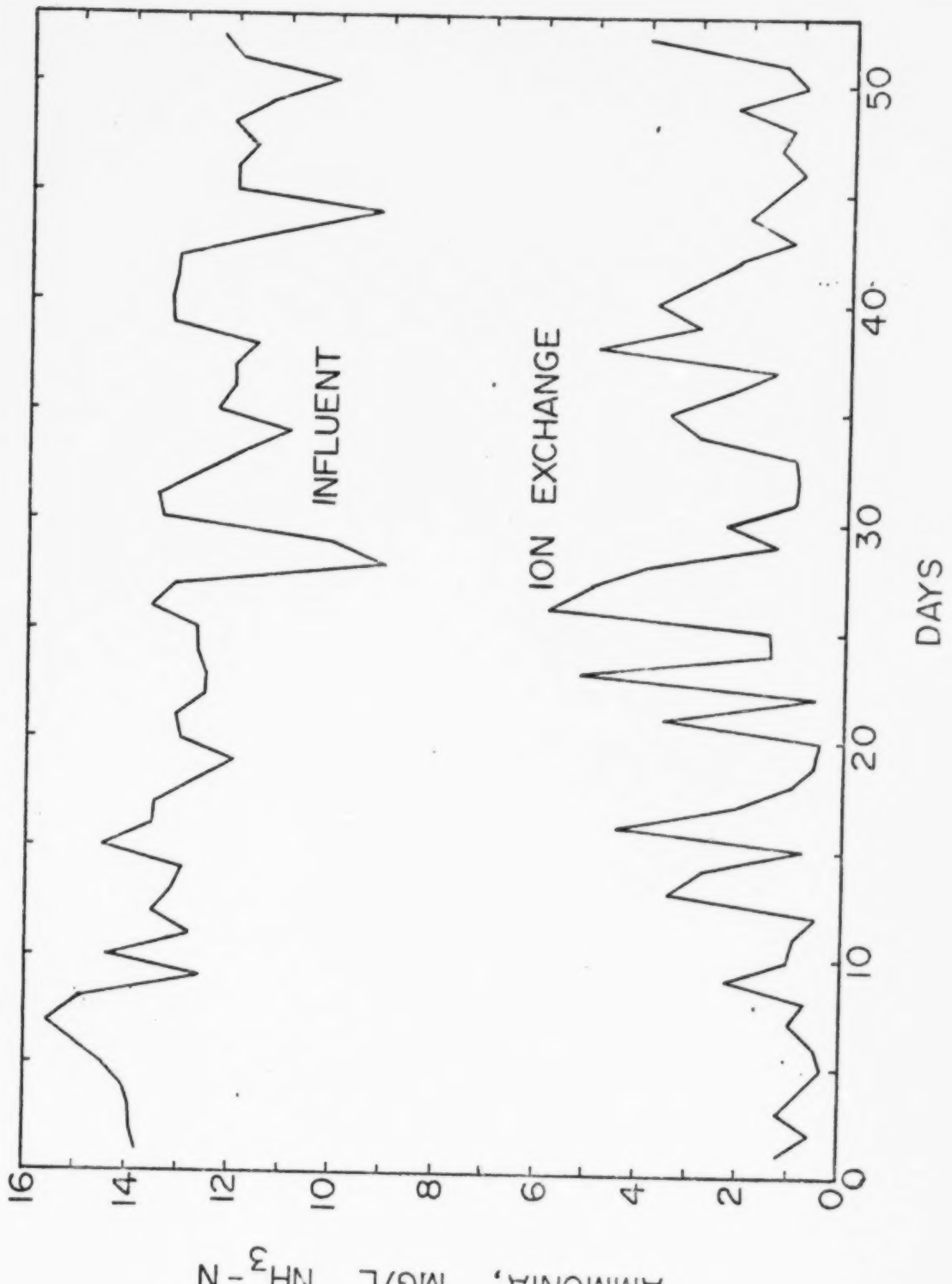

PHOSPHORUS, MG/L P
0
1
2
3
4
5
6
7
8
9
10
11
MAY
JUNE
JULY
INFLUENT
CLARIFIED

FIGURE 6. - Removals of Ammonia by Ion Exchange


AMMONIA, MG/L NH_3-N
0
2
4
6
8
10
12
14
16
0
10
20
30
40
50
DAYS
INFLUENT
ION EXCHANGE